How well can we estimate the displacements associated to loading ?

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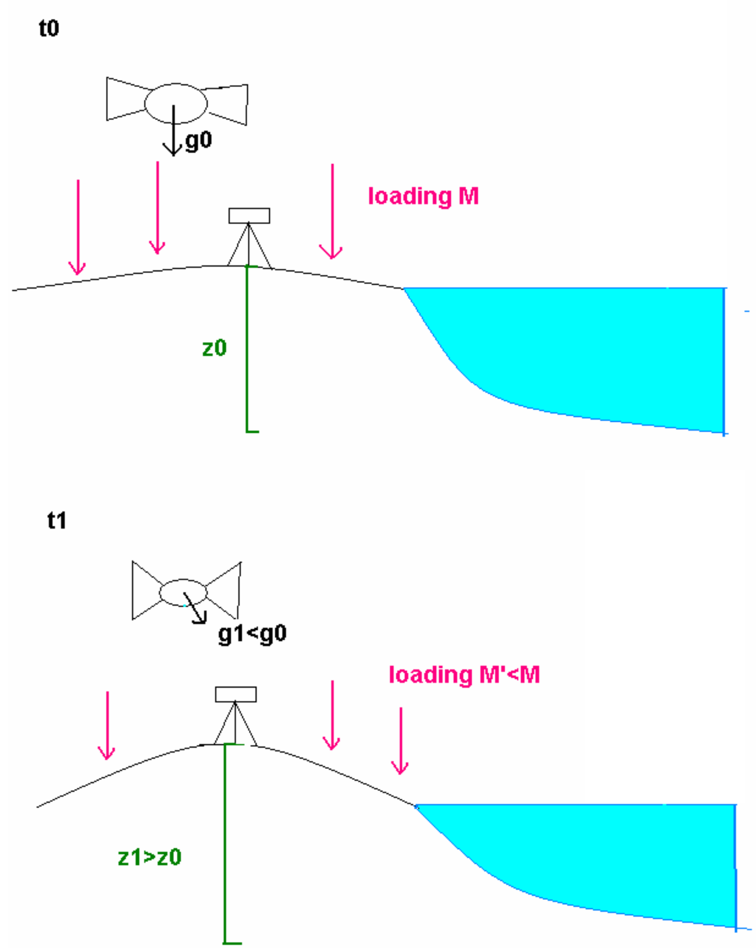
Thanks to : Xavier Collilieux (IGN/LAREG), Juliette Legrand (ORB)

Introduction

The geodetic techniques (GRACE, GPS) and the global loading models are precise, but have no real competitor to be compared with



GRACE, GPS and load models have a common source of variability (the surface load)

Use this redundancy for precision assessment of the load displacements.

southern Europe : dense permanent GPS network

Summary

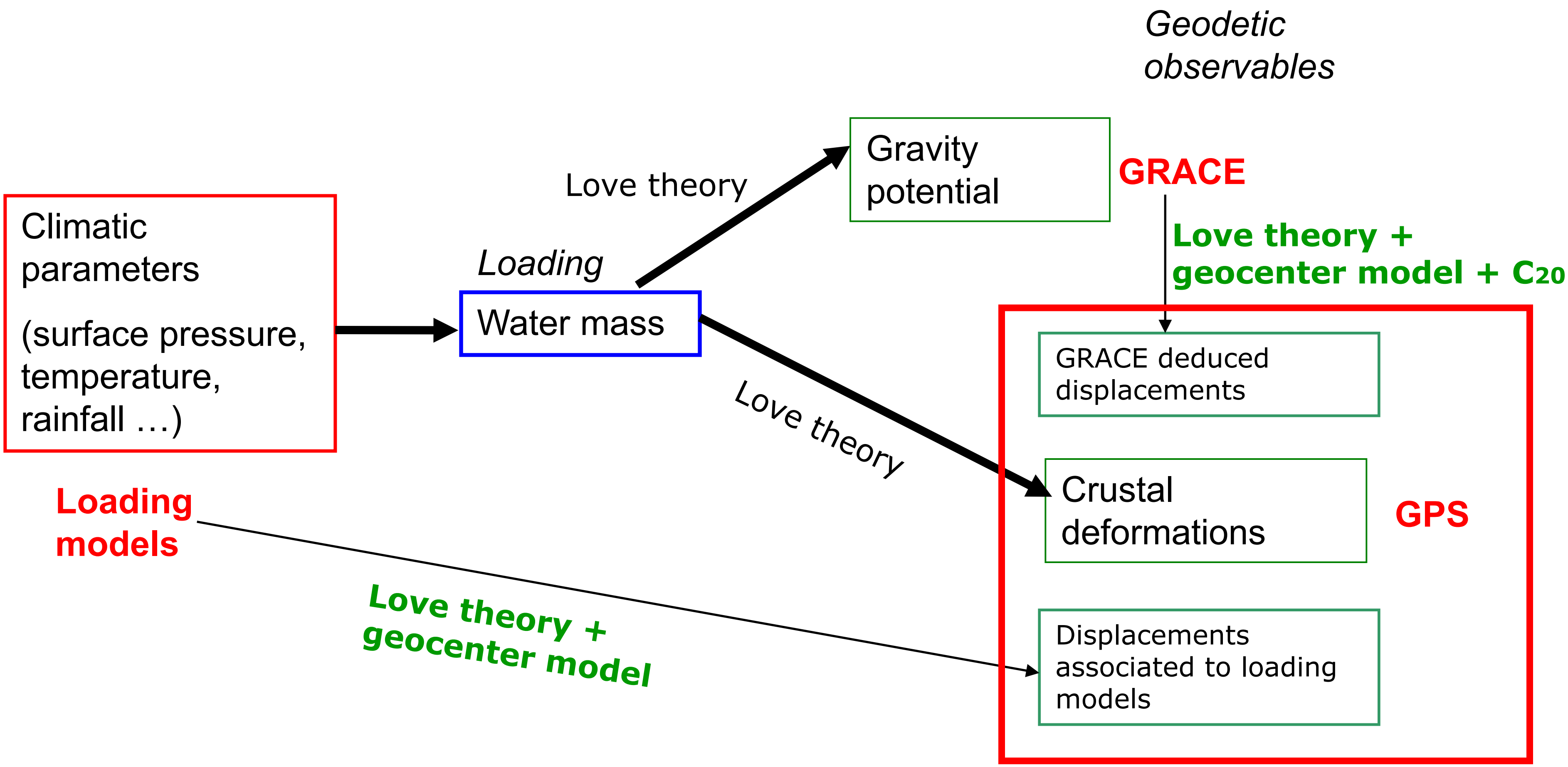
Introduction

I . Link between loading phenomenons and geodetic measurements

II . Evaluating the residuals on the loading estimation

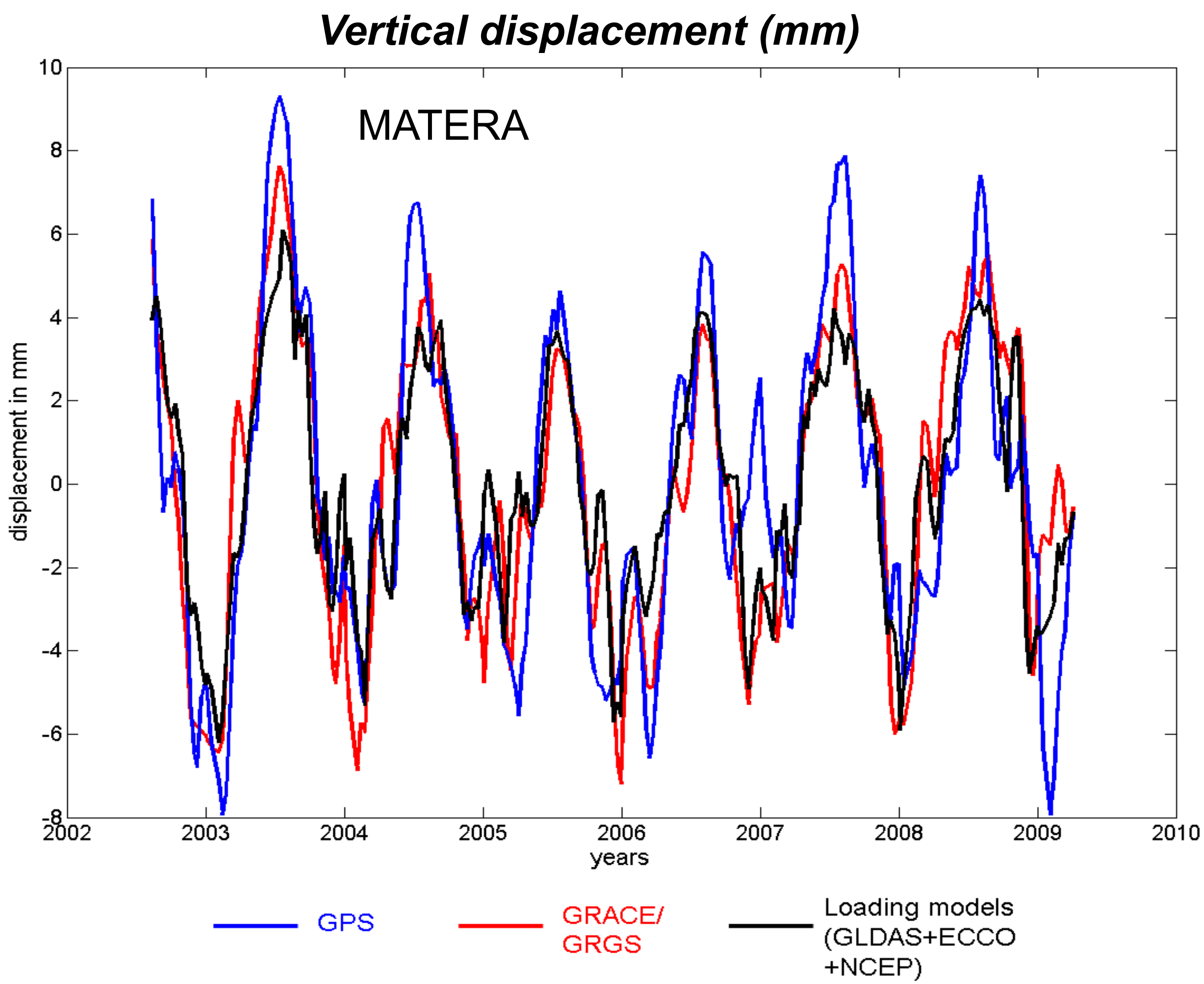
Conclusion

I. The link between loading phenomenons and geodetic measurements



+removing means and trends

Total displacement



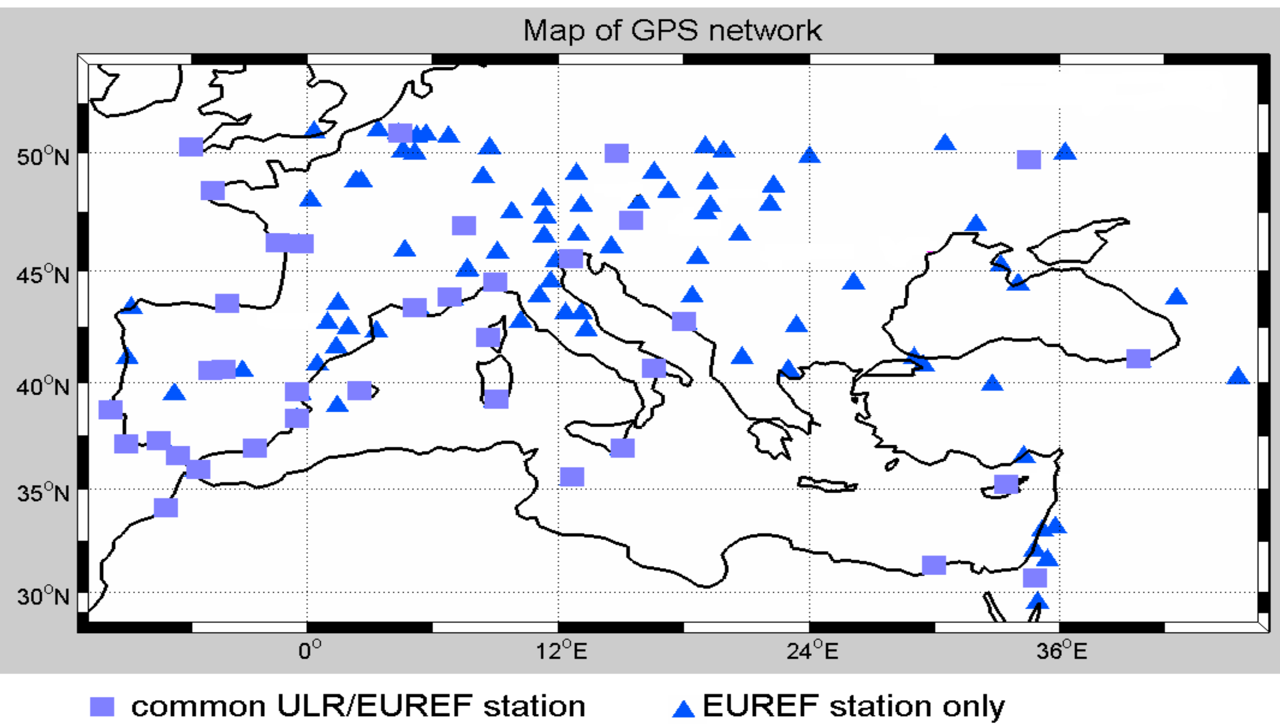
The geodetic observables : GPS

2 solutions used :

- European reprocessed dense solution EUREF, combined with a weekly reprocessed global solution (IGb) (Collilieux et al., 2011)

- Global solution ULR4 (Alvaro Santamaria).

We select stations with more of 75% of available weekly measurements on the common time span with GRACE (2002.3 – 2010)



Result : time series of displacement of 110 EUREF stations and 36 ULR stations

The loading models

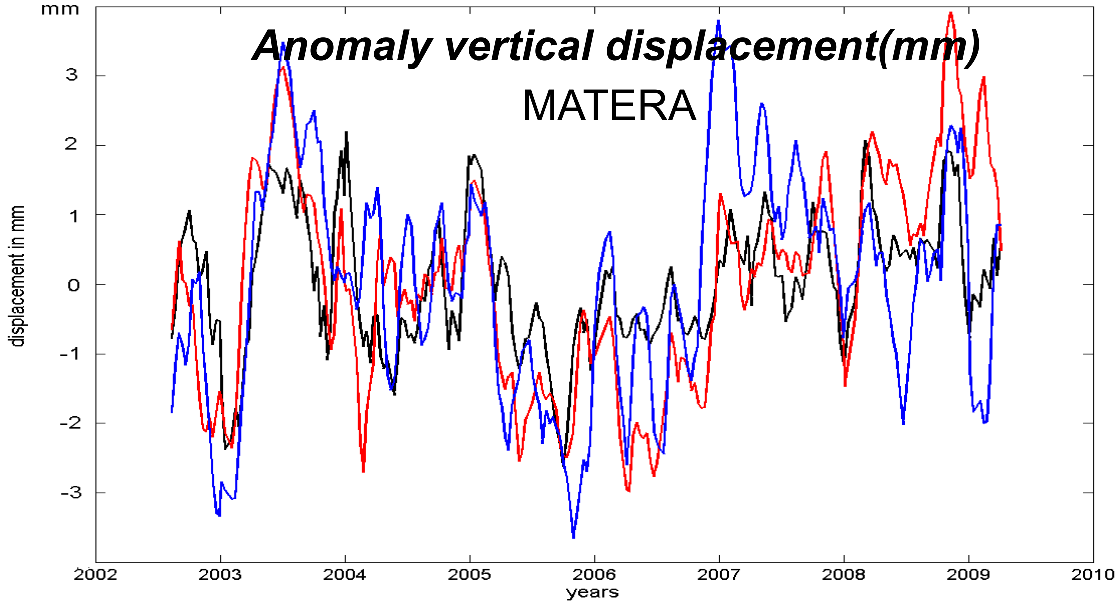
-**Hydrology models:** mass distributions .
GLDAS, WGHM

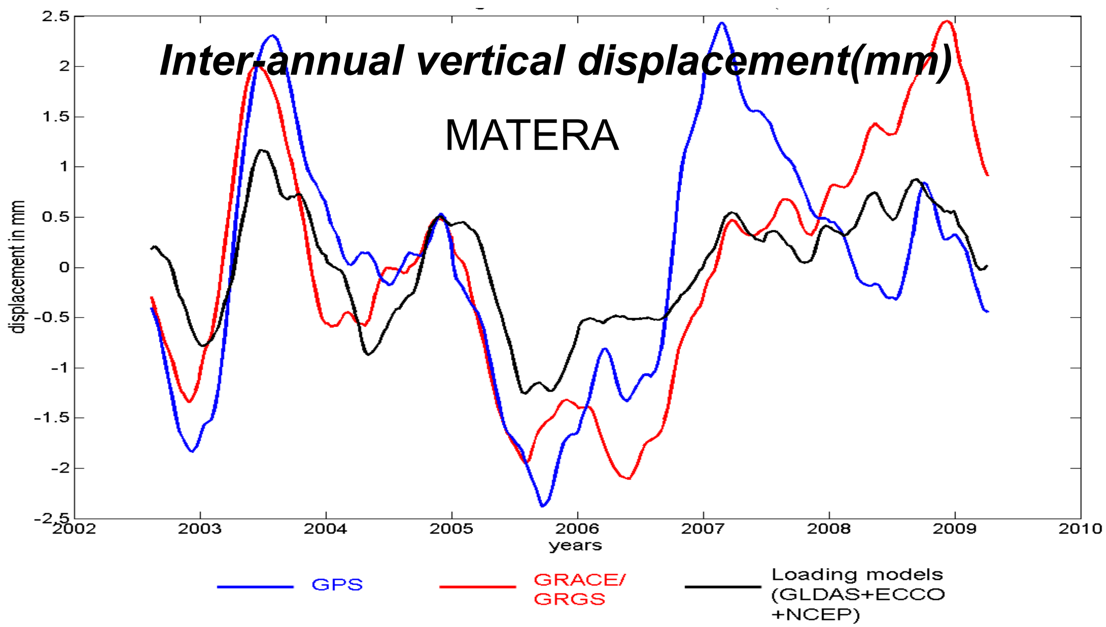
- **Atmospheric models** : surface pressure
NCEP (Petrov and Boy)

- **Oceanic models** : Ocean Bottom Pressure
ECCO, Mercator

None of the models assimilates GRACE or GPS data.

Inter-annual displacements





1) Removing annual composite signal

2) Filtering (removing periods < 6 months).

= inter-annual signal

Introduction

I . Link between loading phenomenons and geodetic measurements

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Conclusion

II . Evaluating the residuals for the loading deformation

3 independant datasets of vertical displacements in response to a common source of variability :

-GPS (2 different solutions European combined & ULR4),

- computed from GRACE (solutions : CSR, GFZ, JPL et GRGS),

- computed from the load models (4 combinations).

On 110 stations

Use of the three-cornered hat method

(Gray et Allan, 1974)

The three-cornered hat method

For each displacement, we can write : $D_i = D_{true} + \varepsilon_i$

Time serie of displacement from the dataset *xi*

Displacement due to the common source

Residual for dataset *xi*

$$\begin{aligned}\mathrm{var}(D_i - D_j) &= \mathrm{var}(D_{true} + \varepsilon_i - D_{true} - \varepsilon_j)\\ &= \mathrm{var}(\varepsilon_i - \varepsilon_j)\\ &= \mathrm{var}(\varepsilon_i) + \mathrm{var}(\varepsilon_j) - 2\,\mathrm{cov}(\varepsilon_i, \varepsilon_j)\end{aligned}$$

Independant observations → covariance of the residuals is null

$$\boxed{\mathrm{var}(D_{gps} - D_{GRACE})} = \sigma_{gps}^2 + \boxed{\sigma_{GRACE}^2}$$

$$\boxed{\mathrm{var}(D_{\text{modèles}} - D_{GRACE})} = \boxed{\sigma_{\text{modèles}}^2} + \sigma_{GRACE}^2$$

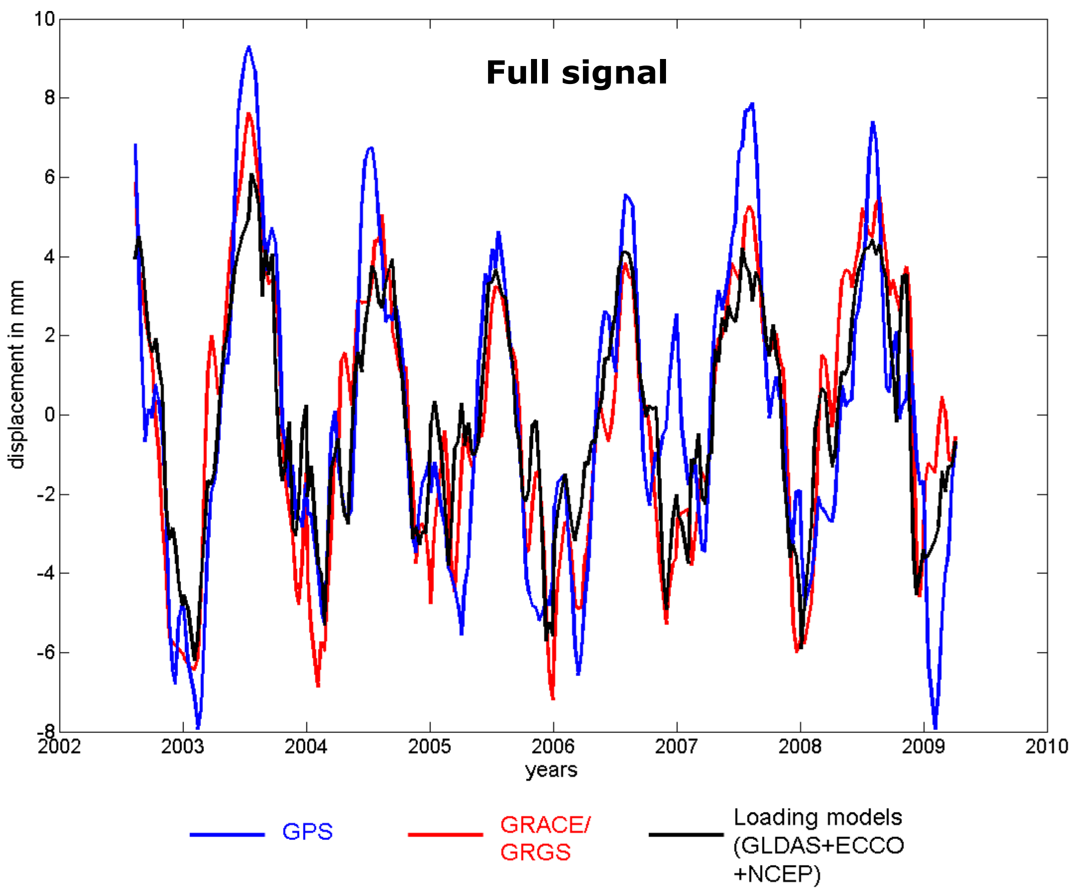
$$\underbrace{\boxed{\mathrm{var}(D_{gps} - D_{\text{modèles}})}}_{\text{3 observations}} = \underbrace{\boxed{\sigma_{gps}^2} + \sigma_{\text{modèles}}^2}_{\text{3 unknowns}}$$

For several solutions of the same dataset, covariances have to be estimated

$$\mathrm{var}(D_{GRACE_{GRGS}} - D_{GRACE_{CSR}}) = \boxed{\sigma_{GRACE_{GRGS}}^2} + \boxed{\sigma_{GRACE_{CSR}}^2} + 2\boxed{\mathrm{cov}(\varepsilon_{GRACE_{GRGS}}, \varepsilon_{GRACE_{CSR}})}$$

Example of MATERA station

Estimation of the variance of the differences between the 3 time series and the common signal (the large and medium scale loading)



$\sigma_{gps} = 1.65$ mm

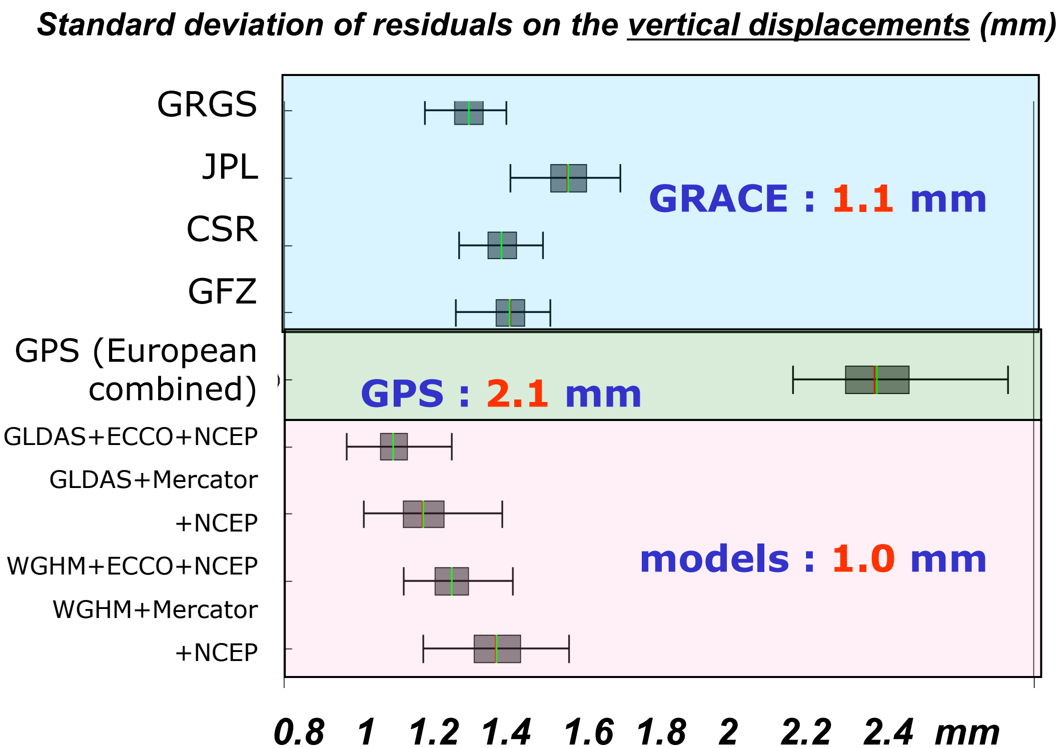
$\sigma_{GRACE-GRGS} = 0.81$ mm

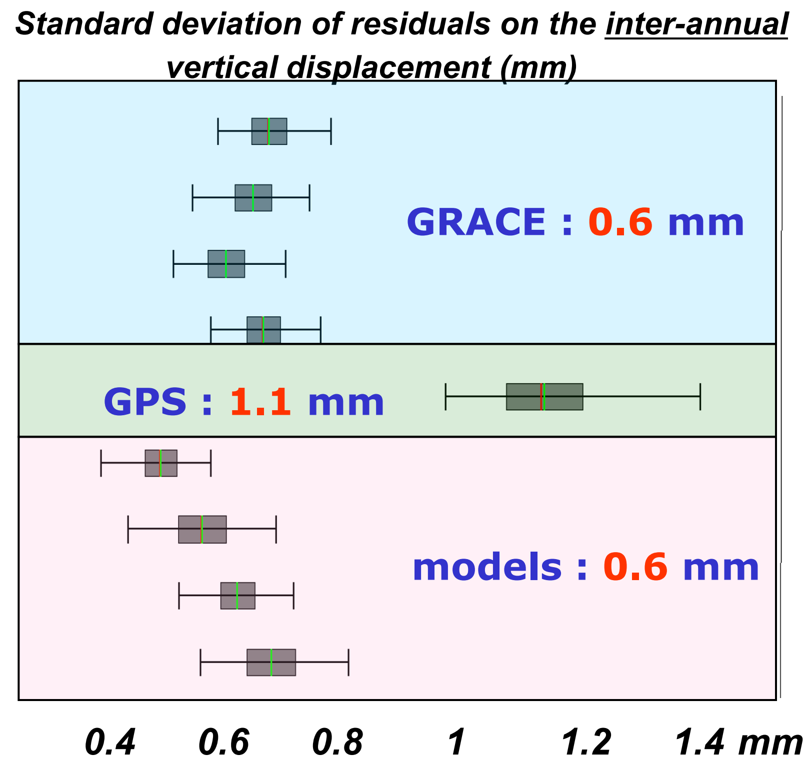
$\sigma_{GLDAS+ECCO+NCEP} = 0.62$ mm

Standard deviation of the residuals at the same order for the 3 datasets.

GPS residuals slightly larger (better consistency between GRACE and the sum of models)

Global results (on full network)





Standard deviation of the residuals at the same order for GRACE and the models (both on total than on inter-annual signal) and 2 times larger for GPS

Mean standard deviation of the time series : GRACE : 3.2 mm GPS : 3.9 mm loading models : 3.0 mm

GRACE inter-annual : 1.3 mm GPS inter-annual : 1.9 mm loading models inter-annual : 1.1 mm

Global results (on full network)

Differences between the GRACE solutions on total vertical signal : GRGS give the lower residuals when signal is dominated by annual component

GRACE inter-annual : all the models are similar

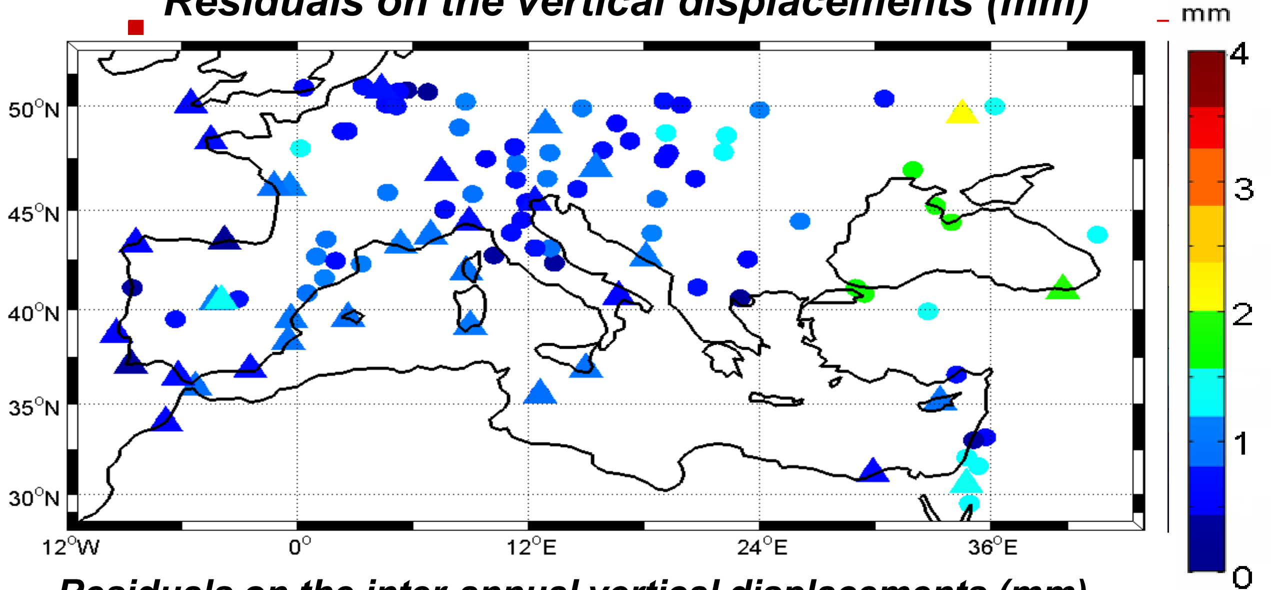
Loading models : differences, both on total than on inter-annual signal (using GLDAS and ECCO give better results)

GPS : two solutions (European combined and ULR4) are consistent at better than 0.1 mm

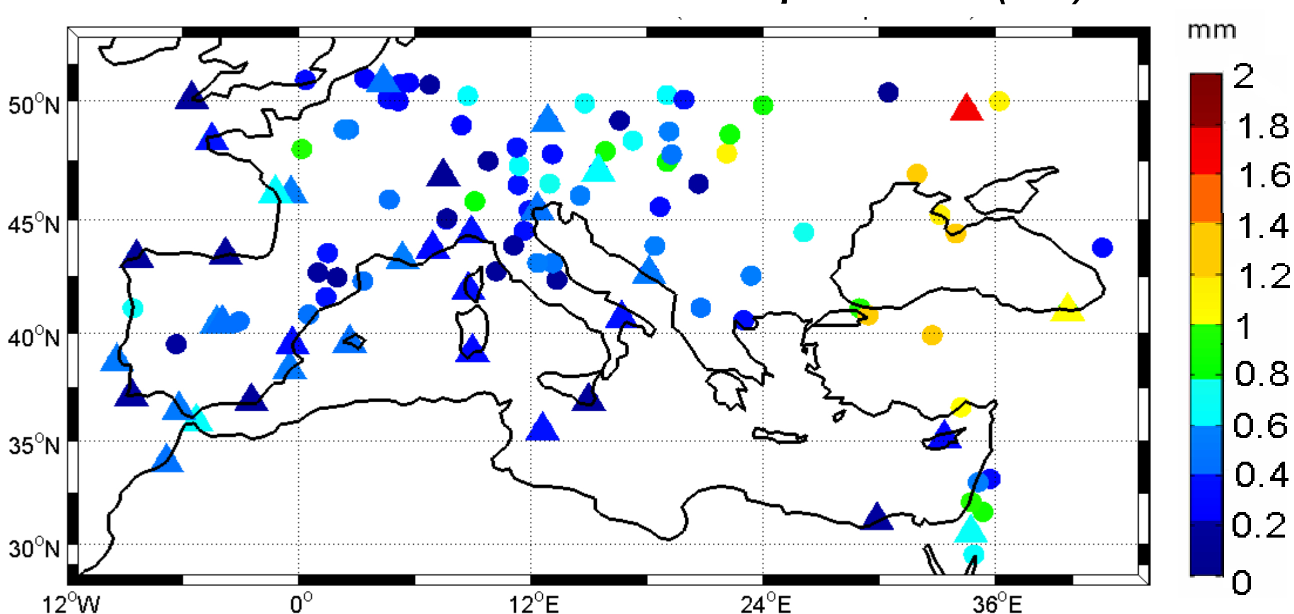
Applications :
- choosing the best GRACE solution or the best combination of models for loading correction

The residual term for the loading models

Residuals on the vertical displacements (mm)



Residuals on the inter-annual vertical displacements (mm)



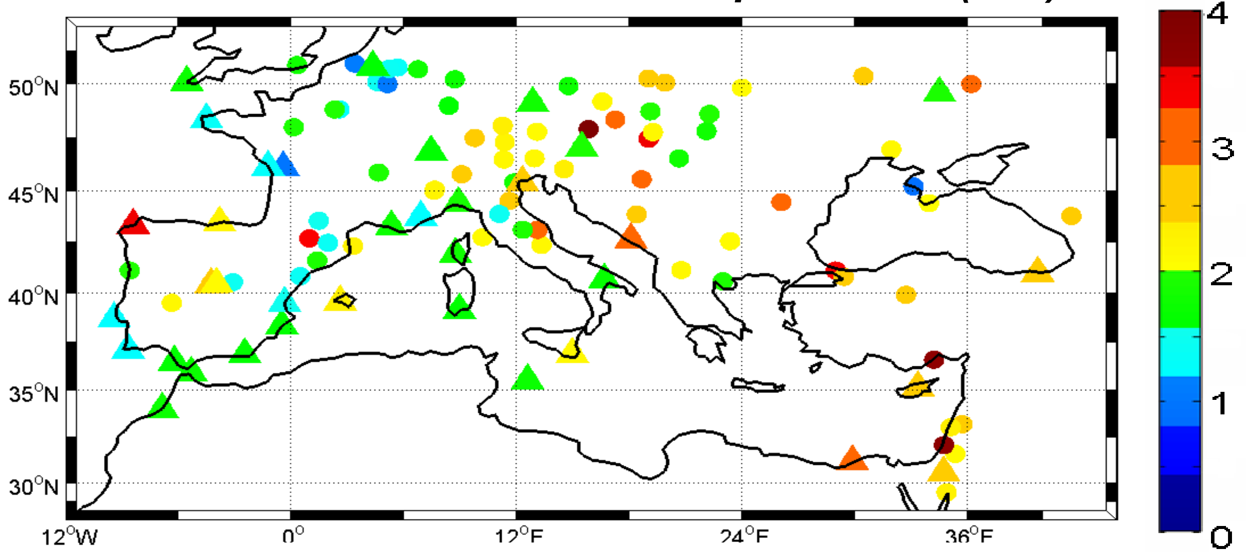
- Mean relative residual (ratio between the variance of the residuals and the variance of the signal) of **12% on total signal** and around **30% on inter-annual signal**

-Small errors everywhere, excepted around the Black Sea (mismodelling of oceanic loading), and Middle East

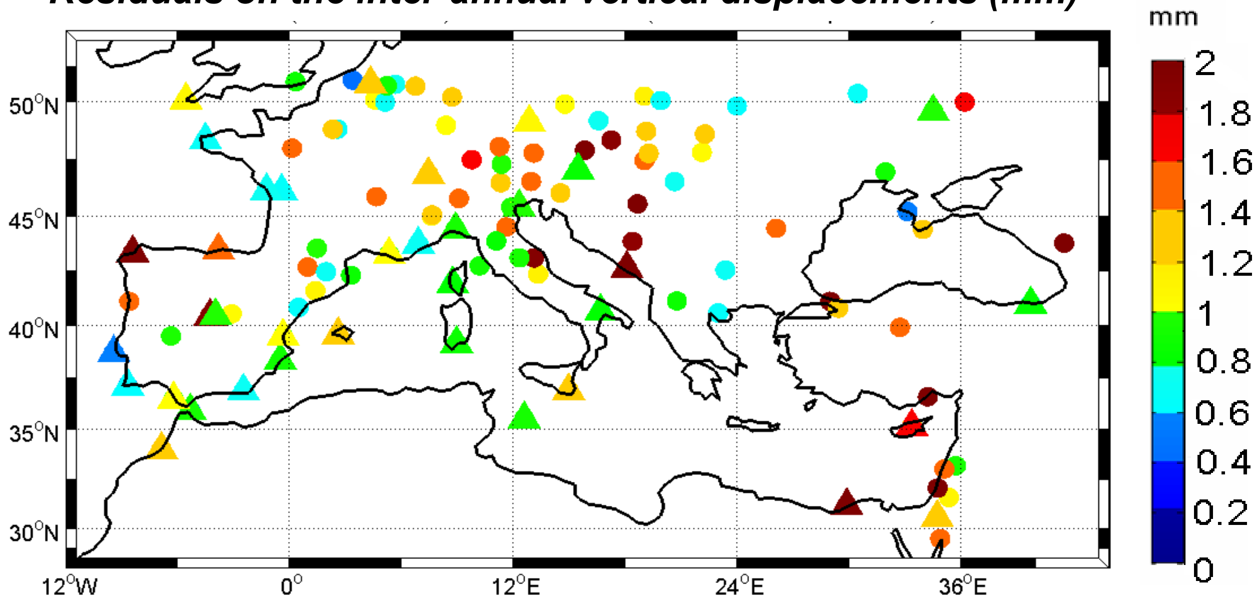
- Application : detecting inconsistencies of models

The residual term for GPS

Residuals on the vertical displacement (mm)



Residuals on the inter-annual vertical displacements (mm)



- **No clear spatial pattern**

Total signal

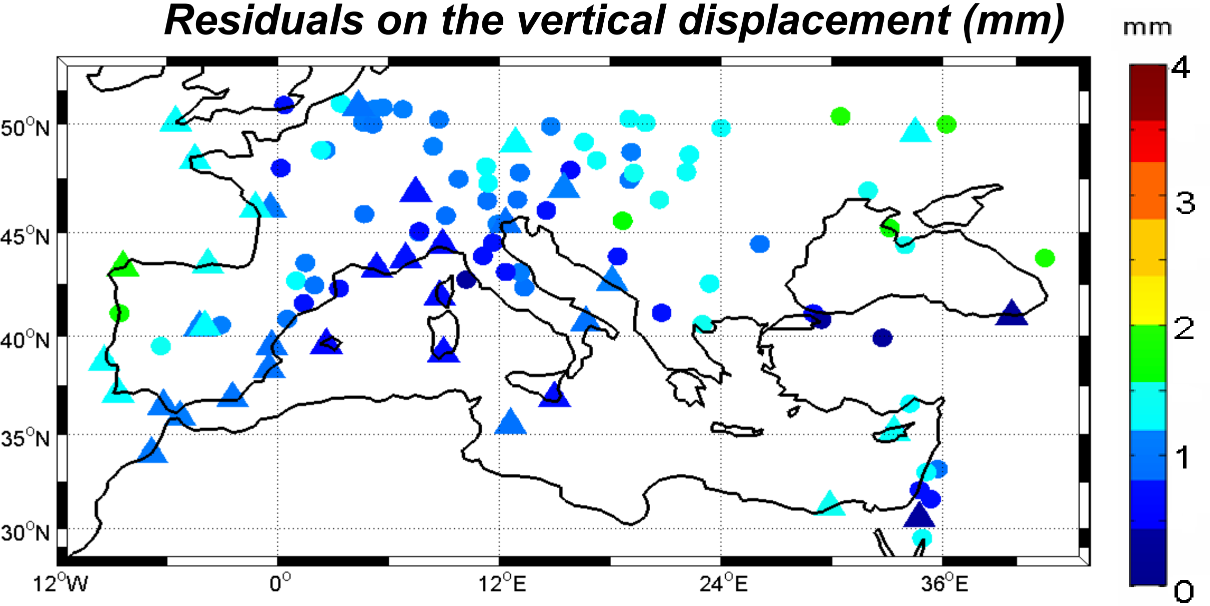
- **Mean relative residual of 31%**
- **On all stations (except 3 outliers), the loading explains at least half of the variance of the time serie**
- **Application: detecting outliers, strong local effects**

Inter-annual signal

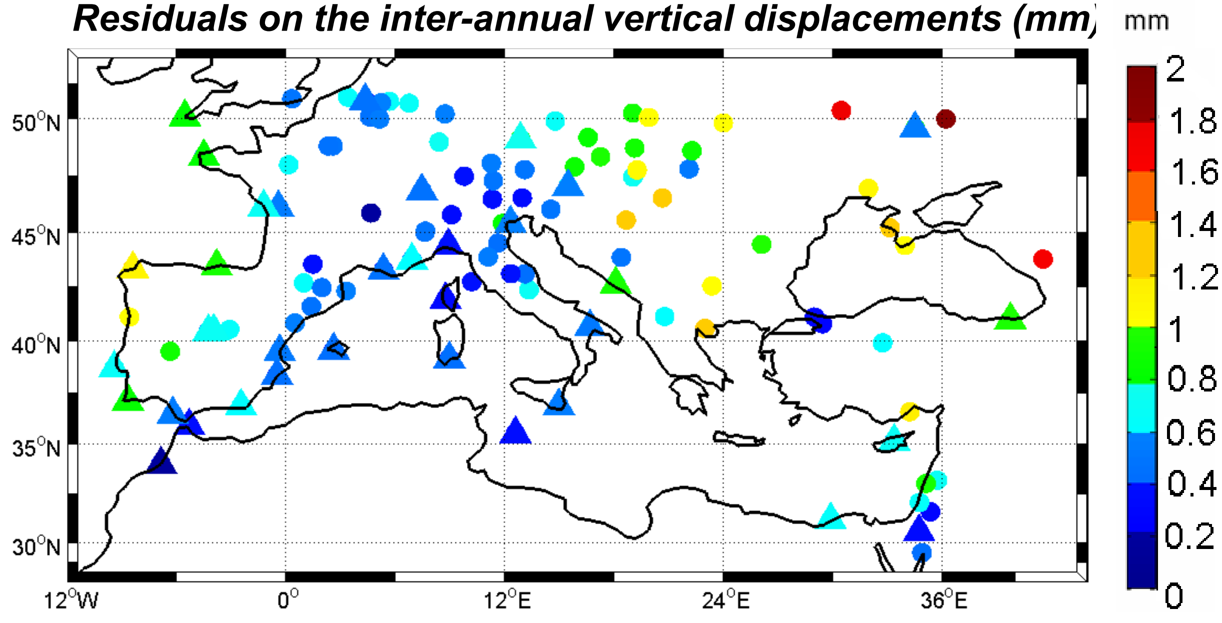
- **GPS inter-annual signal variance partly explained by the common inter-annual loading on 80% of stations**

The residual term for GRACE

Residuals on the vertical displacement (mm)



Residuals on the inter-annual vertical displacements (mm)



Total signal

Map of spatial errors rather homogeneous, excepted on Atlantic coast and in Ukraine

Mean relative residuals similar to the models

Inter-annual signal

Mean relative inter-annual residual of 31%

Interpretation of the residual term

$$D_i = D_{true} + \varepsilon_i$$

The three-cornered hat method aims at estimating the variance of the residual term, which represents the differences between the signal and a « true » loading (which is considered as the common signal between the three datasets).

This residual term contains everything which is not common tour our three datasets. This includes :

- the noise and the errors of the considered technic or model (or missing contributions like groundwater in the hydrology models..),but also…

- the difference of spatial resolution between the considered dataset and the common loading (mainly local loading effects in GPS)

- physical effects not linked with the loading in the time series :

GPS : local geologic motions, thermal expansion, post-seismic effects (secular tectonic effects removed by the trend)

Conclusion

- The three-cornered hat method allowed an estimation of the residuals for measuring the loading on our 3 datasets.

- **Determining which GRACE/GPS/combination of models solution give better results. Application to the strategy of correction of load effects in time series**

- **Detecting inconsistencies and errors on models (regional scale) or strong local effects in GPS**

- **GPS vertical displacements are dominated by the large and medium scale loading. This study allows a better understanding of GPS displacements, specially at inter-annual time scales (possible application to ITRF stations)**

- Horizontal signal : GPS time series are dominated by other effects than loading (but GRACE and models are consistent each other)

Tricorne généralisé

- Techniques indépendantes (covariance des erreurs nulle)

Vrai en première approximation (GPS et GRACE : techniques géodésiques indépendantes, et les modèles de surcharge n'assimilent ni données GRACE ni GPS)

Vérification de la véracité de l'hypothèse : utilisation du tricorne généralisé : hypothèse de covariances faibles mais non nulles (ajout de contraintes).

Résultats : - corrélations des erreurs inter-techniques (ex : GPS – GRACE) estimées inférieures à 0.2.

- variances estimées équivalentes celles obtenues avec le tricorne classique (écart < 0.1 mm)

Conclusion

This study aimed at quantifying the part of the large and medium scale loading in the geodetic time series.

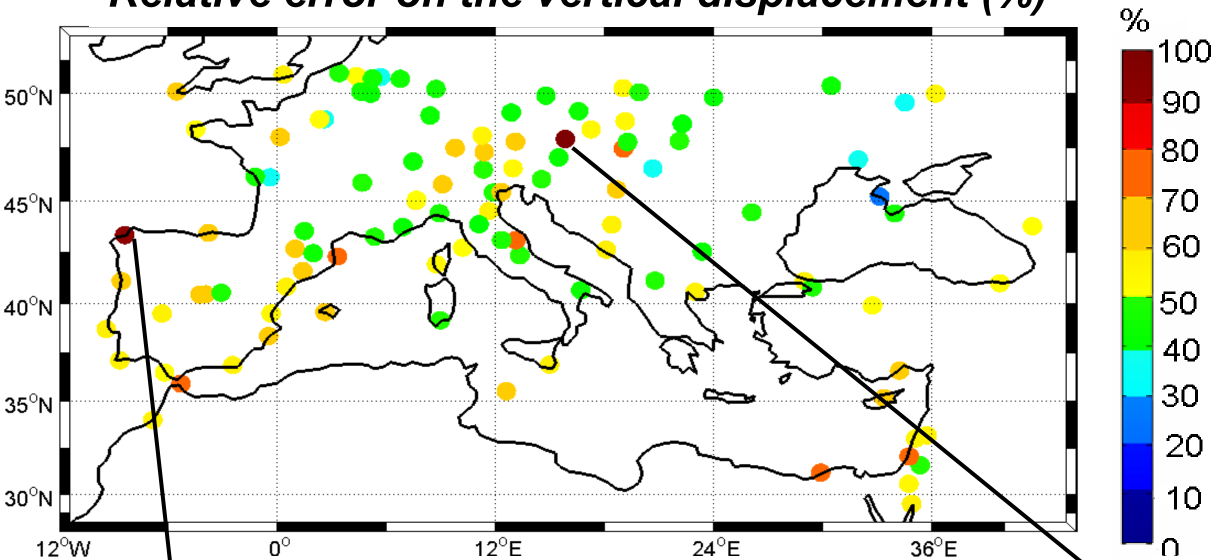
Applications :

Understanding GPS non-linear displacements and specially inter-annual ones. Noise analysis of geodetic time series.

Longer term : combined GRACE/GPS loading solution in Southern Europe

GPS – total signal

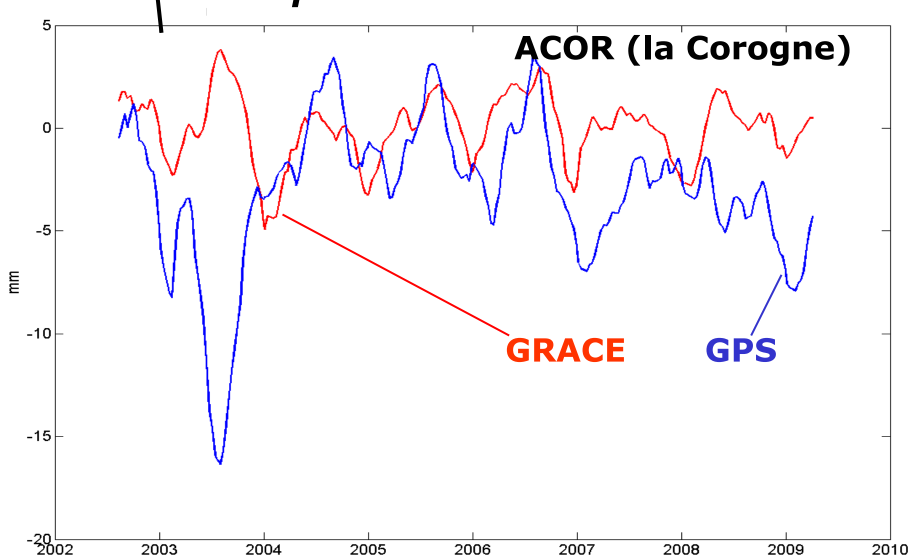
Relative error on the vertical displacement (%)



- Spatial repartition of errors is homogeneous, but we notice 2 outliers

- Application : detection of outliers (or forgotten discontinuities…)

Displacement in mm



Displacement in mm